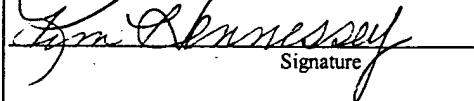


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**APPLICATION FOR LETTERS PATENT**

**FOR**

**MULTI-ZONE COMPLETION STRINGS AND METHODS FOR MULTI-ZONE  
COMPLETIONS**

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## TITLE OF THE INVENTION

Multi-Zone Completion Strings and Methods for Multi-Zone Completions

## BACKGROUND OF THE INVENTION

5 The present invention relates to the field of well completion assemblies for use in a wellbore. More particularly, the invention provides a method and apparatus for completing and producing from multiple mineral production zones, independently or in any combination.

10 The need to drain multiple-zone reservoirs with marginal economics using a single well bore has driven new downhole tool technology. While many reservoirs have excellent production potential, they cannot support the economic burden of an expensive deepwater infrastructure. Operators needed to drill, complete and tieback subsea completions to central production facilities and remotely monitor, produce and manage the drainage of multiple horizons. This requires rig mobilization (with its associated costs running into millions of dollars) to shut off or prepare to produce additional zones from the central production facility.

15 Another problem with existing technology is its inability to complete two or more zones in a single well while addressing fluid loss control to the upper zone when running the well completion hardware. In the past, expensive and often undependable chemical fluid loss pills were spotted to control fluid losses into the reservoir after perforating and/or sand control treatments. A concern with this method when completing upper zones is the inability to effectively remove these pills, negatively affecting the formation and production potential and reducing production efficiency. Still another problem is economically completing and producing from different production zones at different stages in a process, and in differing combinations. The existing technology dictates an inflexible order of process steps for completion and production.

20 Prior systems required the use of a service string, wire line, coil tubing, or other implement to control the configuration of isolation valves. Utilization of such systems involves positioning of tools down-hole. Certain disadvantages have been identified with the systems of the prior art. For example, prior conventional isolation systems have had to be installed after the

gravel pack, thus requiring greater time and extra trips to install the isolation assemblies. Also, prior systems have involved the use of fluid loss control pills after gravel pack installation, and have required the use of through-tubing perforation or mechanical opening of a wireline sliding sleeve to access alternate or primary producing zones. In addition, the installation of prior 5 systems within the wellbore require more time consuming methods with less flexibility and reliability than a system which is installed at the surface. Each trip into the wellbore adds additional expense to the well owner and increases the possibility that tools may become lost in the wellbore requiring still further operations for their retrieval.

While pressure actuated valves have been used in certain situations, disadvantages have 10 been identified with such devices. For example, prior pressure actuated valves had only a closed position and an open position. Thus, systems could not reliably use more than one such valve, since the pressure differential utilized to shift the first valve from the closed position to the open would be lost once the first valve was opened. Therefore, there could be no assurance all valves in a system would open.

15 There has therefore remained a need for an isolation system for well control purposes and for wellbore fluid loss control, which combines simplicity, reliability, safety and economy, while also affording flexibility in use.

## SUMMARY OF THE INVENTION

20 The present invention provides a system which allows an operator to, perforate, complete, and produce multiple production zones from a single well in a variety of ways allowing flexibility in the order of operation. An isolation system of the present invention does not require tools to shift the valve and allows the use of multiple pressure actuated valves in a production assembly.

25 According to one aspect of the invention, after a zone is completed, total mechanical fluid loss is maintained and the pressure-actuated circulating (PAC) and/or pressure-actuated device (PAD) valves are opened with pressure from the surface when ready for production. This eliminates the need to rely on damaging and sometimes non-reliable fluid loss pills being spotted

in order to control fluid loss after the frac or gravel pack on an upper zone (during the extended time process of installing completion production hardware).

According to another aspect of the present invention, the economical and reliable exploitation of deepwater production horizons that were previously not feasible are within  
5 operational limits of a system of the invention.

A further aspect of the invention provides an isolation sleeve assembly which may be installed inside a production screen and thereafter controlled by generating a pressure differential between the valve interior and exterior.

According to a still another aspect of the invention, there is provided a string for  
10 completing a well, the string comprising: a base pipe comprising a hole; at least one packer in mechanical communication with the base pipe; at least one screen in mechanical communication with the base pipe, wherein the at least one screen is proximate the hole in the base pipe; an isolation pipe concentric within the base pipe and proximate to the hole in the base pipe, wherein an annulus is defined between the base pipe and the isolation pipe; and an annulus-to-annulus  
15 valve in mechanical communication with the base pipe and the isolation pipe.

Another aspect of the invention provides a system for completing a well, the system comprising: a first string comprising: a first base pipe comprising a hole, at least one first packer in mechanical communication with the first base pipe, at least one first screen in mechanical communication with the first base pipe, wherein the at least one first screen is  
20 proximate the hole in the first base pipe, a first isolation pipe concentric within the first base pipe and proximate to the hole in the first base pipe, wherein a first annulus is defined between the first base pipe and the first isolation pipe, and a first annulus-to-annulus valve in mechanical communication with the first base pipe and the first isolation pipe; and a second string which is stingable into the first string, the second string comprising: a second base pipe comprising a hole, at least one second screen in mechanical communication with the second base pipe, wherein the at least one second screen is proximate the hole in the second base pipe, a second isolation pipe concentric within the second base pipe and proximate to the hole in the second base pipe, wherein a second annulus is defined between the second base pipe and the second  
25

isolation pipe, and a second annulus-to-annulus valve in mechanical communication with the second base pipe and the second isolation pipe.

According to an aspect of the invention, there is provided a system for completing a well, the system comprising: a first string comprising: a first base pipe comprising a hole, at least one first packer in mechanical communication with the first base pipe, at least one first screen in mechanical communication with the first base pipe, wherein the at least one first screen is proximate the hole in the first base pipe, a first isolation pipe concentric within the first base pipe and proximate to the hole in the first base pipe, wherein a first annulus is defined between the first base pipe and the first isolation pipe, and a first annulus-to-annulus valve in mechanical communication with the first base pipe and the first isolation pipe; and a second string which is stingable into the first string, the second string comprising: a second base pipe comprising a hole, at least one second screen in mechanical communication with the second base pipe, wherein the at least one second screen is proximate the hole in the second base pipe, a second isolation pipe concentric within the second base pipe and proximate to the hole in the second base pipe, wherein a second annulus is defined between the second base pipe and the second isolation pipe, and a second annulus-to-annulus valve in mechanical communication with the second base pipe and the second isolation pipe; and a third string which is stingable into the second string, the third string comprising: a third base pipe comprising a hole, at least one third screen in mechanical communication with the third base pipe, wherein the at least one third screen is proximate the hole in the third base pipe, a third isolation pipe concentric within the third base pipe and proximate to the hole in the third base pipe, wherein a third annulus is defined between the third base pipe and the third isolation pipe, and a third annulus-to-annulus valve in mechanical communication with the third base pipe and the third isolation pipe.

According to a further aspect of the invention, there is provided a method for completing multiple zones, the method comprising: setting a first string in a well proximate a first production zone, wherein the first string comprises: a first base pipe comprising a hole, at least one first packer in mechanical communication with the first base pipe, at least one first screen in mechanical communication with the first base pipe, wherein the at least one first screen is

proximate the hole in the first base pipe, a first isolation pipe concentric within the first base pipe and proximate to the hole in the first base pipe, wherein a first annulus is defined between the first base pipe and the first isolation pipe, and a first annulus-to-annulus valve in mechanical communication with the first base pipe and the first isolation pipe; performing at least one completion operation through the first string; isolating the first production zone with the first string; and producing fluids from the first production zone.

According to a further aspect of the invention, there is provided a method for completing multiple zones, the method comprising: setting a first string in a well proximate a first production zone, wherein the first string comprises: a first base pipe comprising a hole, at least one first packer in mechanical communication with the first base pipe, at least one first screen in mechanical communication with the first base pipe, wherein the at least one first screen is proximate the hole in the first base pipe, a first isolation pipe concentric within the first base pipe and proximate to the hole in the first base pipe, wherein a first annulus is defined between the first base pipe and the first isolation pipe, and a first annulus-to-annulus valve in mechanical communication with the first base pipe and the first isolation pipe; performing at least one completion operation through the first string; isolating the first production zone with the first string; and producing fluids from the first production zone; stinging a second string into the first string and setting the second string proximate a second production zone, wherein the second string comprises: a second base pipe comprising a hole, at least one second screen in mechanical communication with the second base pipe, wherein the at least one second screen is proximate the hole in the second base pipe, a second isolation pipe concentric within the second base pipe and proximate to the hole in the second base pipe, wherein a second annulus is defined between the second base pipe and the second isolation pipe, and a second annulus-to-annulus valve in mechanical communication with the second base pipe and the second isolation pipe; performing at least one completion operation through the second string; and producing fluids from the second production zone through the second string.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is better understood by reading the following description of non-limitative embodiments with reference to the attached drawings wherein like parts in each of the several figures are identified by the same reference characters, and which are briefly described as follows.

Figures 1A through 1I illustrate a cross-sectional, side view of first and second isolation strings.

Figures 2A through 2L illustrate a cross-sectional, side view of first, second and third isolation strings, wherein the first and second strings co-mingle production fluids.

Figures 3A through 3K illustrate a cross-sectional, side view of first, second and third isolation strings, wherein the second and third strings co-mingle production fluids.

Figures 4A through 4N illustrate a cross-sectional, side view of first, second, third and fourth isolation strings, wherein the first and second strings co-mingle production fluids and the third and fourth strings co-mingle production fluids.

Figures 5A through 5J are a cross-sectional side view of a pressure actuated device (PAD) valve shown in an open configuration.

Figures 6A through 6J are a cross-sectional side view of the PAD valve of Figure 5A through 5J shown in a closed configuration so as to restrict flow through the annulus.

Figures 7A through 7D are a side, partial cross-sectional, diagrammatic view of a pressure actuated circulating (PAC) valve assembly in a locked-closed configuration. It will be understood that the cross-sectional view of the other half of the production tubing assembly is a mirror image taken along the longitudinal axis.

Figures 8A through 8D illustrate the isolation system of Figure 7 in an unlocked-closed configuration.

Figures 9A through 9D illustrate the isolation system of Figure 8 in an open configuration.

Figure 10 is a cross-sectional, diagrammatic view taken along line A-A of Figure 9C showing the full assembly.

Figures 11A through 11D illustrate a cross-sectional side view of a first isolation string.

Figure 12A through 12I illustrate a cross-sectional side view of a second isolation string stung into the first isolation string shown in Figure 11.

Figures 13A through 13L illustrate a cross-sectional side view of a third isolation string 5 stung into the second isolation string shown in Figure 12, wherein the first isolation string is also shown.

Figures 14A through 14L illustrate a cross-sectional side view of the first, second and third isolation strings shown in Figures 11 through 13, wherein a production string is stung into the third isolation string.

10 It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, as the invention may admit to other equally effective embodiments.

#### DETAILED DESCRIPTION OF THE INVENTION

15 For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated 20 therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Referring to Figures 1A through 1I, there is shown a system for production over two separate zones. A first isolation string 11 is placed adjacent the first production zone 1. A second isolation string 22 extends across the second production zone 2. The first isolation string 25 11 enables gravel pack, fracture and isolation procedures to be performed on the first production zone 1 before the second isolation string 22 is placed in the well. After the first production zone 1 is isolated, the second isolation string 22 is stung into the first isolation string 11. Without running any tools on wire line or coil tubing to manipulate any of the valves, the second isolation

string 22 enables gravel pack, fracture and isolation of the second production zone 2. The first and second isolation strings 11 and 22 operate together to allow simultaneous production of zones 1 and 2 without co-mingling the production fluids. The first production zone 1 produces fluid through the interior of the production pipe or tubing 5 while the second production zone 2 produces fluid through the annulus between the production tubing 5 and the well casing (not shown).

The first isolation string 11 comprises a production screen 15 which is concentric about a base pipe 16. At the lower end of the base pipe 16 there is a lower packer 10 for engaging the first isolation string 11 in the well casing (not shown). Within the base pipe 16, there is a 10 isolation or wash pipe 17 which has an isolation valve 18 therein. A pressure-actuated device (PAD) valve 12 is attached to the tops of both the base pipe 16 and the isolation pipe 17. The PAD valve 12 allows fluid communication through the annuluses above and below the PAD valve. A pressure-actuated circulating (PAC) valve 13 is connected to the top of the PAD valve 12. The PAC valve allows fluid communication between the annulus and the center of the string. 15 Further, an upper packer 19 is attached to the exterior of the PAD valve 12 through a further section of base pipe 16. This section of base pipe 16 has a cross-over valve 21 which is used to communicate fluid between the inside and outside of the base pipe 16 during completion operations.

Once the first isolation string 11 is set in the well casing (not shown) by engaging the 20 upper and lower packers 19 and 10, fracture and gravel pack operations are conducted or may be conducted on the first production zone. To perform a gravel pack operation, a production tube (not shown) is stung into the top of a sub 14 attached to the top of the PAC valve 13. Upon completion of the gravel pack operation, the isolation valve 18 and the PAD valve 12 are closed to isolate the first production zone 1. The tubing is then withdrawn from the sub 14. The second 25 isolation string 22 is then stung into the first isolation string 11. The second isolation string comprises a isolation pipe 27 which stings all the way into the sub 14 of the first isolation string 11. The second isolation string 22 also comprises a base pipe 26 which stings into the upper packer 19 of the first isolation string 11. The second isolation string 22 also comprises a

production screen 25 which is concentric about the base pipe 26. A PAD valve 23 is connected to the tops of the base pipe 26 and isolation pipe 27. The isolation pipe 27 also comprises isolation valve 28. Attached to the top of the PAD valve 23 is a sub 30 and an upper packer 29 which is connected through a section of pipe. Production tubing 5 is shown stung into the sub 30. The section of base pipe 26 between the packer 29 and the PAD valve 23 also comprises a cross-over valve 31.

Since the second isolation string 22 stings into the upper packer 19 of the first isolation string 11, it has no need for a lower packer. Further, since the first isolation string 11 has been gravel packed and isolated, the second production zone 2 may be fractured and gravel packed independent of the first production zone 1. As soon as the completion procedures are terminated, the isolation valves 28 and the PAD valve 23 are closed to isolate the second production zone 2.

The production tubing 5 is then stung into the sub 30 for production from either or both of zones 1 or 2. For example, production from zone 1 may be accomplished simply by opening isolation valve 18 and allowing production fluid from zone 1 to flow through the center of the system up through the inside of production tubing 5. Alternatively, production from only zone 2 may be accomplished by opening isolation valve 28 to similarly allow production fluids from zone 2 to flow up through the inside of production tubing 5.

Non-commingled simultaneous production is accomplished by closing isolation valve 18 and opening PAD valve 12 and PAC valve 13 to allow zone 1 production fluids to flow to the inside of the system and up through the center of production tubing 5. At the same time, PAD valve 23 may be opened to allow production fluids from zone 2 to flow through the annulus between production tubing 5 and the casing.

The first isolation string 11 comprises a PAD valve 12 and a PAC valve 13. The second isolation string 22 comprises a PAD valve 23 but does not comprise a PAC valve. PAD valves enable fluid production through the annulus formed on the outside of a production tube. PAC valves enable fluid production through the interior of a production tube. These valves are discussed in greater detail below.

Referring to Figures 2A through 2L, an isolation system is shown comprising three separate isolation strings. In this embodiment of the invention, the first production string 11 comprises a lower packer 10 and a base pipe 16 which is connected to the lower packer 10. A production screen 15 is concentric about the base pipe 16. A isolation pipe 17 extends through 5 the interior of the base pipe 16 and has an isolation valve 18 thereon. The PAD valve 12 of the first isolation string is attached to the tops of the base pipe 16 and isolation pipe 17. In this embodiment of the invention, a sub 14 is attached to the top of the PAD valve 12. The first isolation string 11 also comprises an upper packer 19 which is connected to the top of the PAD 10 valve 12 through a length of base pipe 16. The length of base pipe 16 has therein a cross-over valve 21.

The second isolation string 22 is stung into the first isolation string 11 and comprises a base pipe 26 with a production screen 25 therearound. Within the base pipe 26, there is a isolation pipe 27 which is stung into the sub 14 of the first isolation string 11. The isolation pipe 27 comprises isolation valve 28. Further, the base pipe 26 is stung into the packer 19 of the first 15 isolation string 11. The second isolation string 22 comprises a PAD valve 23 which is attached to the tops of the base pipe 26 and isolation pipe 27. A PAC valve 24 is attached to the top of the PAD valve 23. Further, a sub 30 is attached to the top of the PAC valve 24. An upper packer 29 is attached to the top of the PAD valve 23 through a section of base pipe 26 which further comprises a cross-over valve 31.

20 The third isolation string 32 is stung into the top of the second isolation string 22. The third isolation string 32 comprises a base pipe 36 with a production screen 35 thereon. Within the base pipe 36, there is a isolation pipe 37 which has an isolation valve 38 therein. Attached to the tops of the base pipe 36 and isolation pipe 37, there is a PAD valve 33. A sub 40 is attached to the top of the PAD valve on the interior, and a packer 39 is attached to the exterior of the PAD 25 valve 33 through a section of base pipe 36. A production tubing 5 is stung into the sub 40.

The first isolation string 11 comprises a PAD valve 12 but does not comprise a PAC valve. The second isolation string 22 comprises both a PAD valve 23 and a PAC valve 24. The third isolation string 32 only comprises a PAD valve 33 but does not comprise a PAC valve.

This production system enables sequential gravel pack, fracture and isolation of zones 1, 2 and 3. Also, this system enables fluid from production zones 1 and 2 to be co-mingled and produced through the interior of the production tubing, while the fluid from the third production zone is produced through the annulus around the exterior of the production tube.

5       The co-mingling of fluids produced by the first and second production zones is effected as follows: PAD valves 12 and 23 are opened to cause the first and second production zone fluids to flow through the production screens 15 and 25 and into the annulus between the base pipes 16 and 26 and the isolation pipes 17 and 27. This co-mingled fluid flows up through the opened PAD valves 12 and 23 to the bottom of the PAC valve 24. PAC valve 24 is also opened  
10      to allow this co-mingled fluid of the first and second production zones 1 and 2 to flow from the annulus into the center of the base pipes 16 and 26 and the sub 30. All fluid produced by the first and second production zones through the annulus is forced into the production tube 5 interior through the open PAC valve 24.

15      Production from the third production zone 3 is effected by opening PAD valve 33. This allows production fluids to flow up through the annulus between the base pipe 36 and the isolation pipe 37, up through the PAD valve 33 and into the annulus between the production tube 5 and the well casing (not shown).

20      Referring to Figures 3A through 3K, a system is shown wherein a first isolation string 11 comprises a PAD valve 12 and a PAC valve 13. This first isolation string 11 is similar to that previously described with reference to Figure 1. The second isolation string 22 comprises only a PAD valve 23 and is similar to the second isolation string described with reference to Figure 1. The third isolation string 32 comprises only a PAD valve 33 but no PAC valve and is also similar to the second isolation string described with reference to Figure 1. This configuration enables production from zone 1 to pass through the PAC valve into the interior of the annulus of the production tubing. The fluids from production zones two and three co-mingle and are produced through the annulus about the exterior of the production tube.  
25

The co-mingling of fluids produced by the second and third production zones is effected as follows: Opening PAD valves 23 and 33 creates an unimpeded section of the annulus. Fluids produced through PAD valves 23 and 33 are co-mingled in the annulus.

Referring to Figures 4A through 4N, a system is shown comprising four isolation strings.

5 The first isolation string 11 comprises a PAD valve 12 but no PAC valve. The second isolation string 22 comprises a PAD valve 23 and a PAC valve 24. The third isolation string 32 comprises a PAD valve 33 but does not comprise a PAC valve. Similarly the fourth isolation string 42 comprises a PAD valve 43 but does not comprise a PAC valve. In this particular configuration, production fluids from zones one and two are co-mingled for production through the PAC valve

10 into the interior of the production tube 5. The fluids from production zones three and four are co-mingled for production through the annulus formed on the outside of the production tube 5.

In this embodiment, the first isolation string 11 is similar to the first isolation string shown in Figure 2. The second isolation string 22 is also similar to the second isolation string shown in Figure 2. The third isolation string is also similar to the third isolation string shown in

15 Figure 2. However, rather than having a production tubing 5 stung into the top of the third isolation string, the embodiment shown in Figure 4, comprises a fourth isolation string 42. The fourth isolation string comprises a base pipe 46 with a production screen 45 therearound. On the inside of the base pipe 46, there is a isolation pipe 47 which has an isolation valve 48. Attached to the tops of the base pipe 46 and the isolation pipe 47, there is a PAD valve 43. To the interior of the top of the PAD valve 43, there is attached a sub 50. To the exterior of the PAD valve 43, there is attached through a section of base pipe 46, an upper packer 49, wherein the section of base pipe 46 comprises a cross-over valve 51. A production tubing 5 is stung into the sub 50.

Referring to Figures 5A through 5J and 6A through 6J, detailed drawings of a PAD valve are shown. In Figure 5, the valve is shown in an open position and in Figure 6, the valve is shown in a closed position. In the open position, the valve enables fluid communication through the annulus between the interior and exterior tubes of the isolation string. Essentially, these interior and exterior tubes are sections of the base pipe 16 and the isolation pipe 17. The PAD valve comprises a shoulder 52 that juts into the annulus between two sealing lands 58. The

should 52 is separated from each of the sealing lands 58 by relatively larger diameter troughs 60. The internal diameters of the shoulder 52 and the sealing lands 58 are about the same. A moveable joint 54 is internally concentric to the shoulder 52 and the sealing lands 58. The moveable joint 54 also has seals 56 which contact sealing lands 58 and the shoulder 52. The 5 movable joint 54 has a spanning section 62 and a closure section 64, wherein the outside diameter of the spanning section 62 is less than the outside diameter of the closure section 64.

The valve is in a closed position, when the valve is inserted in the well. The PAD valve is held in the closed position by a shear pin 55. A certain change in fluid pressure in the annulus will cause the moveable joint 54 to shift, opening the PAD valve by losing the contact between 10 the joint 54 and the shoulder 52. Since the relative diameters of the spanning section 62 and closure section 64 are different, the annulus pressure acts on the moveable joint 54 to slide the moveable joint 54 to a position where the spanning section 62 is immediately adjacent the shoulder 52. Since the outside diameter of the spanning section 62 is less than the inside diameter of the shoulder 52, fluid flows freely around the shoulder 52 and through the PAD 15 valve.

As shown in Figure 6, in the closed position, the PAD valve restricts flow through the annulus. Here, the PAD valve has contact between the shoulder 52 and the moveable joint 54, forming a seal to block fluid flow through the annulus at the PAD valve.

Referring to Figs. 7A through 7D, there is shown a production tubing assembly 110 according to the present invention. The production tubing assembly 110 is mated in a conventional manner and will only be briefly described herein. Assembly 110 includes 20 production pipe 140 that extends to the surface and a production screen assembly 112 with PAC valve assembly 108 controlling fluid flow through the screen assembly. In a preferred embodiment production screen assembly 112 is mounted on the exterior of PAC valve assembly 25 108. PAC valve assembly 108 is interconnected with production tubing 140 at the uphole end by threaded connection 138 and seal 136. Similarly on the downhole end 169, PAC valve assembly 108 is interconnected with production tubing extension 113 by threaded connection 122 and seal 124. In the views shown, the production tubing assembly 110 is disposed in well casing 111 and

has inner tubing 114, with an internal bore 115, extending through the inner bore 146 of the assembly.

The production tubing assembly 110 illustrates a single preferred embodiment of the invention. However, it is contemplated that the PAC valve assembly according to the present invention may have uses other than at a production zone and may be mated in combination with a wide variety of elements as understood by a person skilled in the art. Further, while only a single isolation valve assembly is shown, it is contemplated that a plurality of such valves may be placed within the production screen depending on the length of the producing formation and the amount of redundancy desired. Moreover, although an isolation screen is disclosed in the preferred embodiment, it is contemplated that the screen may include any of a variety of external or internal filtering mechanisms including but not limited to screens, sintered filters, and slotted liners. Alternatively, the isolation valve assembly may be placed without any filtering mechanisms.

Referring now more particularly to PAC valve assembly 108, there is shown outer sleeve upper portion 118 joined with an outer sleeve lower portion 116 by threaded connection 128. For the purpose of clarity in the drawings, these openings have been shown at a 45° inclination. Outer sleeve upper portion 118 includes two relatively large production openings 160 and 162 for the flow of fluid from the formation when the valve is in an open configuration. Outer sleeve upper portion 118 also includes through bores 148 and 150. Disposed within bore 150 is shear pin 151, described further below. The outer sleeve assembly has an outer surface and an internal surface. On the internal surface, the outer sleeve upper portion 118 defines a shoulder 188 (FIG. 7C) and an area of reduced wall thickness extending to threaded connection 128 resulting in an increased internal diameter between shoulder 188 and connection 128. Outer sleeve lower portion 116 further defines internal shoulder 189 and an area of reduced internal wall thickness extending between shoulder 189 and threaded connection 122. Adjacent threaded connection 138, outer sleeve portion 118 defines an annular groove 176 adapted to receive a locking ring 168.

Disposed within the outer sleeves is inner sleeve 120. Inner sleeve 120 includes production openings 156 and 158 which are sized and spaced to correspond to production openings 160 and 162, respectively, in the outer sleeve when the valve is in an open configuration. Inner sleeve 120 further includes relief bores 154 and 142. On the outer surface 5 of inner sleeve there is defined a projection defining shoulder 186 and a further projection 152. Further inner sleeve 120 includes a portion 121 having a reduced external wall thickness. Portion 121 extends down hole and slidably engages production pipe extension 113. Adjacent uphole end 167, inner sleeve 120 includes an area of reduced external diameter 174 defining a shoulder 172.

10 In the assembled condition shown in FIG. 7A through 7D, inner sleeve 120 is disposed within outer sleeves 116 and 118, and sealed thereto at various locations. Specifically, on either side of production openings 160 and 162, seals 132 and 134 seal the inner and outer sleeves. Similarly, on either side of shear pin 151, seals 126 and 130 seal the inner sleeve and outer sleeve. The outer sleeves and inner sleeve combine to form a first chamber 155 defined by 15 shoulder 188 of outer sleeve 118 and by shoulder 186 of the inner sleeve. A second chamber 143 is defined by outer sleeve 116 and inner sleeve 120. A spring member 180 is disposed within second chamber 143 and engages production tubing 113 at end 182 and inner sleeve 120 at end 184. A lock ring 168 is disposed within recess 176 in outer sleeve 118 and retained in the recess by engagement with the exterior of inner sleeve 120. Lock ring 168 includes a shoulder 20 170 that extends into the interior of the assembly and engages a corresponding external shoulder 172 on inner sleeve 120 to prevent inner sleeve 120 from being advanced in the direction of arrow 164 beyond lock ring 168 while it is retained in groove 176.

The PAC valve assembly of the present invention has three configurations as shown in FIGS. 7 through 9. In a first configuration shown in FIG. 7, the production openings 156 and 25 158 in inner sleeve 120 are axially spaced from production openings 160 and 162 along longitudinal axis 190. Thus, PAC valve assembly 108 is closed and restricts flow through screen 112 into the interior of the production tubing. The inner sleeve is locked in the closed configuration by a combination of lock ring 168 which prevents movement of inner sleeve 120

up hole in the direction of arrow 164 to the open configuration. Movement down hole is prevented by shear pin 151 extending through bore 150 in the outer sleeve and engaging an annular recess in the inner sleeve. Therefore, in this position the inner sleeve is in a locked closed configuration.

5 In a second configuration shown in FIG. 8A through 8D, shear pin 151 has been severed and inner sleeve 120 has been axially displaced down hole in relation to the outer sleeve in the direction of arrow 166 until external shoulder 152 on the inner sleeve engages end 153 of outer sleeve 116. The production openings of the inner and outer sleeves continue to be axial displaced to prevent fluid flow therethrough. With the inner sleeve axial displaced down hole,  
10 lock ring 168 is disposed adjacent reduced outer diameter portion 174 of inner sleeve 120 such that the lock ring may contract to a reduced diameter configuration. In the reduced diameter configuration shown in FIG. 8, lock ring 168 may pass over recess 176 in the outer sleeve without engagement therewith. Therefore, in this configuration, inner sleeve is in an unlocked position.

15 In a third configuration shown in FIG. 9A through 9D, inner sleeve 120 is axially displaced along longitudinal axis 190 in the direction of arrow 164 until production openings 156 and 158 of the inner sleeve are in substantial alignment with production openings 160 and 162, respectively, of the outer sleeve. Axial displacement is stopped by the engagement of external shoulder 186 with internal shoulder 188. In this configuration, PAC valve assembly 108 is in an  
20 open position.

In the operation of a preferred embodiment, at least one PAC valve according to the present invention is mated with production screen 112 and, production tubing 113 and 140, to form production assembly 110. The production assembly according to FIG. 7 with the PAC valve in the locked-closed configuration, is then inserted into casing 111 until it is positioned adjacent a production zone (not shown). When access to the production zone is desired, a predetermined pressure differential between the casing annulus 144 and internal annulus 146 is established to shift inner sleeve 120 to the unlocked-closed configuration shown in FIG. 8. It will be understood that the amount of pressure differential required to shift inner sleeve 120 is a

function of the force of spring 180, the resistance to movement between the inner and outer sleeves, and the shear point of shear pin 151. Thus, once the spring force and resistance to movement have been overcome, the shear pin determines when the valve will shift. Therefore, the shifting pressure of the valve may be set at the surface by inserting shear pins having different strengths.

A pressure differential between the inside and outside of the valve results in a greater amount of pressure being applied on external shoulder 186 of the inner sleeve than is applied on projection 152 by the pressure on the outside of the valve. Thus, the internal pressure acts against shoulder 186 of to urge inner sleeve 120 in the direction of arrow 166 to sever shear pin 151 and move projection 152 into contact with end 153 of outer sleeve 116. It will be understood that relief bore 148 allows fluid to escape the chamber formed between projection 152 and end 153 as it contracts. In a similar fashion, relief bore 142 allows fluid to escape chamber 143 as it contracts during the shifting operation. After inner sleeve 120 has been shifted downhole, lock ring 168 may contract into the reduced external diameter of inner sleeve positioned adjacent the lock ring. Often, the pressure differential will be maintained for a short period of time at a pressure greater than that expected to cause the down hole shift to ensure that the shift has occurred. This is particularly important where more than one valve according to the present invention is used since once one valve has shifted to an open configuration in a subsequent step, a substantial pressure differential is difficult to establish.

The pressure differential is removed, thereby decreasing the force acting on shoulder 186 tending to move inner sleeve 120 down hole. Once this force is reduced or eliminated, spring 180 urges inner sleeve 120 into the open configuration shown in FIG. 9. Lock ring 168 is in a contracted state and no longer engages recess 176 such the ring now slides along the inner surface of the outer sleeve. In a preferred embodiment spring 180 has approximately 300 pounds of force in the compressed state in FIG. 8. However, varying amounts of force may be required for different valve configurations. Moreover, alternative sources other than a spring may be used to supply the force for opening. As inner sleeve 120 moves to the open configuration, relief bore

154 allows fluid to escape chamber 155 as it is contracted, while relief bores 148 and 142 allow fluid to enter the connected chambers as they expand.

Shown in Figure 10 is a cross-sectional, diagrammatic view taken along line A-A of Figure 9C showing the full assembly.

5        Although only a single preferred PAC valve embodiment of the invention has been shown and described in the foregoing description, numerous variations and uses of a PAC valve according to the present invention are contemplated. As examples of such modification, but without limitation, the valve connections to the production tubing may be reversed such that the inner sleeve moves down hole to the open configuration. In this configuration, use of a spring 180 may not be required as the weight of the inner sleeve may be sufficient to move the valve to the open configuration. Further, the inner sleeve may be connected to the production tubing and the outer sleeve may be slidable disposed about the inner sleeve. A further contemplated modification is the use of an internal mechanism to engage a shifting tool to allow tools to manipulate the valve if necessary. In such a configuration, locking ring 168 may be replaced by 10 a moveable lock that could again lock the valve in the closed configuration. Alternatively, 15 spring 180 may be disengageable to prevent automatic reopening of the valve.

Further, use of a PAC valve according to the present invention is contemplated in many systems. One such system is the ISO System offered by OSCA, Inc. and described in U.S. Patent No. 5,609,204; the disclosure therein is hereby incorporated by reference. A tool shiftable 20 valve may be utilized within the production screens to accomplish the gravel packing operation. Such a valve could be closed as the crossover tool string is removed to isolate the formation. The remaining production valves adjacent the production screen may be pressure actuated valves according to the present invention such that inserting a tool string to open the valves is unnecessary.

25        Figures 11 through 14 illustrate several steps in the construction of an isolation and production system according to an embodiment of the present invention.

Figures 11A through 11D show a first isolation string 211. The isolation string comprises a PAD valve 212. At the lower end of the isolation string 211, there is a lower packer

210 and at the upper end of the isolation string 211 there is an upper packer 219. A base pipe 216 is connected to the lower packer 210 and has a production screen 215 therearound. The isolation string 211 further comprises an isolation valve 218 on a isolation pipe 217. The PAD valve 212 enables fluid communication through the annulus between the isolation pipe 217 and the isolation string 211. The first isolation string 211 also comprises a sub 214 attached to the top of the PAD valve 212. Further, in the base pipe section between the PAD valve 212 and the upper packer 219, there is a cross-over valve 221. This configuration of the first isolation string 211 enables the first production zone 1 to be fractured, gravel packed, and isolated through the first isolation string 211. Upon completion of these procedures, the isolation valve 218 and PAD valve 212 are closed to isolate the production zone 1.

Figures 12A through 12I show cross-sectional, side views of two isolation strings. In particular, a second isolation string 222 is stung inside an isolation string 211. Isolation string 222 comprises a PAD valve 223 and a PAC valve 224. The isolation string 211, shown in this figure, is the same as the isolation string shown in Figure 11. After the gravel/pack and isolation function are performed on the first zone with the isolation string 211, the isolation string 222 is stung into the isolation string 211. The second isolation string 222 comprises a base pipe 226 having a production screen 225 therearound. The base pipe 226 is stung into the packer 219 of the first isolation string 211. The second isolation string 222 also comprises a isolation pipe 227 which is stung into the sub 214 of the first isolation string 211. The isolation pipe 227 also comprises an isolation valve 228. At the tops of the base pipe 226 and isolation pipe 227, there is connected a PAD valve 223. A PAC valve 224 is connected to the top of the PAD valve 223. Also, a sub 230 is attached to the top of the PAC valve 224. An upper packer 229 is also connected to the exterior portion of the PAD valve 223 through a section of base pipe 226 which also comprises a cross-over valve 231.

Referring to Figures 13A through 13L, the isolation strings 211 and 222 of Figure 12 are shown. However, in this figure, a third isolation string 232 is stung into the top of isolation string 222. In this particular configuration, isolation strings 211 and 222 produce fluid from respective zones 1 and 2 up through the annulus between the isolation strings and the isolation

sleeves until the fluid reaches the PAC valve 224. The co-mingled production fluid from production zones 1 and 2 pass through the PAC valve 224 into the interior of the production string. The production fluids from zone 3 is produced through the isolation string 232 up through the annulus between the isolation string 232 and the isolation pipe 237. In the 5 embodiment shown in Figure 13, the PAD valves 212, 223 and 233 are shown in the closed position so that all three of the production zones are isolated. Further, the PAC valve 224 in isolation string 222 is shown in a closed position.

The third isolation string 232 comprises a base pipe 236 which is stung into the packer 229 of the second isolation string. The base pipe 236 also comprises a production screen 235. 10 Inside the base pipe 236, there is a isolation pipe 237 which is stung into the sub 230 of the second isolation string 222. The isolation pipe 237 comprises isolation valve 238. A PAD valve 233 is connected to the tops of the base pipe 236 and isolation pipe 237. A sub 234 is connected to the top of the PAD valve 233. An upper packer 239 is also connected through a section of base pipe 236 to the PAD valve 233. This section of base pipe also comprises a cross-over valve 15 241.

Referring to Figure 14A through 14L, the isolation strings 211, 222 and 232 of Figure 13 are shown. In addition to these isolation strings, a production tube 240 is stung into the top of isolation string 232. With the production tube 240 stung into the system, pressure differential is used to open PAD valves 212, 223, and 233. In addition, the pressure differential is used to set 20 PAC valve 224 to an open position. The opening of these valves enables co-mingled production from zones 1 and 2 through the interior of the production tube while production from zone 3 is through the annulus on the outside of the production tube 240.

The packers, productions screens, isolations valves, base pipes, isolations pipes, subs, cross-over valves, and seals may be off-the-shelf components as are well known by persons of skill in the art. 25

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that

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all changes and modifications that come within the spirit of the invention are desired to be protected.